Renewable and Sustainable Energy Reviews 17 (2013) 83–93

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Fuzzy decision support methodology for sustainable energy crop selection

Ligita Balezentiene [a,*], Dalia Streimikiene [b], Tomas Balezentis [c]

[a] Aleksandras Stulginskis University, Studentu Str. 11, LT-53361 Kaunas distr., Lithuania
[b] Mykolas Romeris University, Ateities Str. 20, LT-08303 Vilnius, Lithuania
[c] Lithuanian Institute of Agrarian Economics, V. Kudirkos Str. 18, LT-03105 Vilnius, Lithuania

ARTICLE INFO

Article history:
Received 30 April 2012
Received in revised form
12 September 2012
Accepted 15 September 2012
Available online 13 October 2012

Keywords:
Biomass production
Energy crop mix
Sustainable energy
Multi-criteria decision making
Fuzzy logics

ABSTRACT

Both strategic and environmental factors make biomass an important energy source and element of sustainable energy policy. The establishment of a reasonable energy crop-mix, indeed, involves various uncertain data. This paper, therefore, offers a multi-criteria decision making framework for prioritization of energy crops based on fuzzy MULTIMOORA method which enables to tackle imprecise information. Given the appropriate energy crop-mix should exhibit both climatic suitability and low environmental pressure, we have defined the indicator set covering respective linguistic and numeric indicators. Accordingly, the set of alternatives were constructed from energy crops suitable for the Lithuanian climate. The fuzzy MULTIMOORA method was employed for data fusion and prioritization. As a result, the prospective species for energy crop-mix were suggested.

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1. Introduction

Renewable energy is one of the key issues of the European (EU) regulations. Accordingly, each of the EU Member States has prepared respective National Renewable Energy Action Plans. As for Lithuania, National Renewable Energy Action Plan (NREAP) treats biomass as the main source of renewable energy, with the largest part, namely 50%, of the biomass energy being subjected to conversion into heat energy there [1]. Biomass heat should constitute the largest share, viz. 75%, of the produced renewable energy, and is the fastest growing energy-mix element between 2005 and 2020 in Lithuanian NREAP. The total share of bioethanol, biodiesel, hydropower, solar energy, and wind power is projected to increase and compose 25% of the total renewable energy in 2020.

Due to strong political support, the production of biofuels from agricultural biomass has been particularly increasing robustly in recent years [2]. There are serious concerns, however, that large-scale bioenergy production from agricultural biomass could lead to additional pressure on the environment and farmland biodiversity.

* Corresponding author. Tel.: +370 37 752 202.
E-mail addresses: ligita.balezentiene@asu.lt (L. Balezentiene), dalia@mail.lei.lt (D. Streimikiene), tomas@laei.lt (T. Balezentis).

1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.09.016

Furthermore, achieving a 30% share of *environmentally orientated* farming (EOF) by 2030 imposes allocation of agricultural land area under environmentally orientated farm management [3]. Thus, to approach the propagation of energy crops from an ecological perspective means to address the environmental aspects of sustainable development. These are mainly related to bioproductivity and potential to produce a certain amount of energy of field crops [4–7]. Thus the actual need is not only to find the acceptable energy crops for renewable energy production in Lithuania. Indeed, what one also needs is to choose an environmentally compatible crop. Therefore the expected effects on environment and biodiversity no similar to those caused by food and feed crops commonly grown on arable farms should be taken into account. Consequently in this study we present the multi-criteria ranking of energy crops with different biological and environmental peculiarities in terms of their agro environmental impact.

MCDM methods deal with problems of compromise selection of the best solutions from the set of available alternatives according to objectives. Usually neither of the alternatives satisfies all the objectives therefore satisfactory decision is made instead of optimal one. Roy [8] presented the following pattern of MCDM problems: (1) α choosing problem—choosing the best alternative; (2) β sorting problem—classifying alternatives into relatively homogenous groups; (3) γ ranking problem—ranking alternatives from best to worst; (4) δ describing problem—describing alternatives in terms of their peculiarities and features. Belton and Stewart [9] defined the three broad categories of MCDM methods [10]: (1) value measurement models; (2) goal, aspiration, and reference level models; (3) outranking models (the French school). In this study we will consider the MULTIMOORA method which encompasses value measurement as well as reference level methods.

The Multi-Objective Optimization by Ratio Analysis (MOORA) was introduced by Brauers and Zavadskas [11]. Subsequently, these authors further developed the method [12] thus presenting the MULTIMOORA (MOORA plus the full multiplicative form). Numerous examples of application of MULTIMOORA are present: the MULTIMOORA was applied in manufacturing and engineering environment [13–15] as well as in economic development studies [16,17]. The theory of dominance [18] enables to summarize the ranks obtained from different parts of MULTIMOORA. Moreover, the MULTIMOORA has been updated with fuzzy number theory [19] and interval number theory [20].

Zadeh, the Founder of fuzzy logic [21], proposed employing the fuzzy set theory as a modeling tool for complex systems that are hard to define exactly in crisp numbers. Fuzzy logic hence allows coping with vague, imprecise and ambiguous input and knowledge [22,23]. Linguistic reasoning relying on fuzzy logics was introduced by Zadeh [24–26] and applied in many studies [27–31].

This paper is, hence, aimed at applying the fuzzy MULTIMOORA for linguistic and numeric reasoning for decision making related to prioritization of energy crops under Lithuanian climatic conditions. The rest of the paper is, therefore, organized in the following way: Section 2 presents the review of literature dealing with assessment of energy crops. Section 3 describes the current EU policy regarding the renewables and energy crops, whereas Section 4 focuses on the Lithuanian energy policy. Section 5 presents the basics of the fuzzy MULTIMOORA method. The following Section 6 describes the criteria and alternatives for multi-criteria energy crop prioritization. Section 7 explains the application of MULTIMOORA for crop prioritization and its results. Finally, conclusions are drawn in Section 8.

2. Literature review

Energy planning problems are complex problems with multiple decision makers and multiple criteria. Therefore, these problems are quite suited to the use of MCDA. A multitude of MCDA methods exists. These methods can be divided into three main groups; value measurement models, goal, aspiration and reference level models, and outranking models. Methods from all of these groups have been applied to energy planning problems, particularly in the evaluation of alternative electricity supply strategies. Each of the methods has its advantages and drawbacks.

As Skolou et al. [32] pointed out, latest energy policy developments reflect the tendency to increase energy production share from renewable energy sources, not only for strategic, but also, for environmental and socio-economic reasons. Biomass production, furthermore, can increase the viability of agricultural business thanks to diversification opportunities. Consequently, a number of studies attempted to offer new insights for renewable energy policy from the agricultural viewpoint. For instance, Havlíčková and Suchý [33] analyzed future prospects of energy crop propagation in the Czech Republic. Đatkov and Effenberger [34] analyzed the efficiency of biogas plants by the means of data envelopment analysis, whereas Madlener et al. [35] additionally employed multi-criteria decision making (MCDM) methods for the latter purpose.

Sustainable bioenergy systems are embedded in social, economic, and environmental contexts and depend on support of many stakeholders with different perspectives. The resulting complexity constitutes a major barrier to the implementation of bioenergy projects. The four tools of Multi Criteria Analysis (*Super Decisions*, *DecideIT*, *Decision Lab*, *NAIADE*) were reviewed for their suitability to assess sustainability of bioenergy systems with a special focus on multi-stakeholder inclusion by Buchholz et al. [36]. Cherni et al. [37] applied the MCDA tool for the selection of the best energy technology for providing sufficient power to fulfill local demands that improve livelihoods in remote areas. The model combines quantitative and qualitative criteria however the model is not able to deal with uncertainties related to linguistic indicators. Tsoutsos et al. [38] applied MCDA method PROMETEE for sustainable energy planning and selection among competing renewable energy options. Compared to fossil energy sources, RES have a lower energy density per unit of land and a stronger dependence from the physical land factors and constraints, therefore a more detailed knowledge of the geographical distribution of the resources is needed to develop future scenarios of renewable energy supply. Among RES, traditional biomass supplies the largest share of global energy consumption. The decision of changing land use for energy purposes should be supported by both a land evaluation under specific environmental conditions, and an assessment of the biological and economic competitiveness of the crops within traditional agricultural and natural landscapes. Such approach requires a lot of data and distinguishes with a lot of uncertainties. The most studies dealing with the problem of prioritization of energy crops have paid the main attention on integration of GIS systems into decision making model [39,40], however uncertainty issues have not been dealt in most of studies. The spatial Decision Support System was also applied for selection among several bio-electricity generation options in Greece [40]. An integrated model incorporating GIS and geo-referenced databases to economic and environmental models was developed, however uncertainty issues related with impact of energy crops on biodiversity and environment were not integrated in this model.

There are many studies dealing with assessment of energy options and using various MCDA techniques. Streimikiene et al. [41] presented the multi-criteria model for assessment of electricity production technologies. The latter study confirmed the superiority of renewable energy sources. Kaya and Kahraman [42] applied modified fuzzy TOPSIS methodology for the selection of the best energy technology alternative. In several scenarios developed for

sensitivity analysis biomass took the first order. The TOPSIS method was also used for evaluation of alternative electricity supply strategies [43]. Ramanathan and Ganesh [44] employed goal programming and AHP to solve an energy resource allocation problem. Afgan and Carvalho [45] applied multi-criteria analysis for ranking of electricity generation plants by developing General Index of Sustainability. This index was calculated for each power plant by normalizing values of sustainability indicators. The renewable energy technologies received the highest ranking in accordance with General Index of Sustainability. Becalli et al. [46] applied the ELECTRE method at regional level for assessment of renewable energy generation options. Other studies also tried to assess the economic, social and environmental indicators and trade-off between them in ranking energy generation options however none of these studies were dealing with energy crops and did not address the problem of uncertainties related to linguistic indicators applied for comparative assessment of energy crops.

The current study furthers the research by proposing a multi-criteria framework for decisions related to energy crop-mix. Although Finco et al. [47] analyzed the issue, the fuzzy logic remains unapplied in the area. Indeed, linguistic reasoning based on fuzzy logic can be a powerful tool to tackle the uncertainty related to sustainable energy policy [48,49]. The current study is new in terms of applying new MCDA tool—Fuzzy Decision Support for ranking of energy crops based on their expected effects on environment and biodiversity which is difficult to quantify. Consequently this study proposes new technique dealing with uncertainties in ranking energy crops with different biological and environmental peculiarities in terms of their agro environmental impact. The fuzzy set theory is a strong tool which can deal with the uncertainty in case of subjective, incomplete, and vague information. It is easier for an energy planning expert to make an evaluation by using linguistic terms therefore the proposed Fuzzy decision support method can be a useful tool in developing biomass projects in agriculture sector.

3. The EU energy policy

The current development process in energy policy is boosted by Commission's Second Strategic Energy Review package in 2008. With regard to the EU energy security and solidarity action plan the Commission figured out five key areas [50]:

- Infrastructure needs and the diversification of energy supplies;
- External energy relations;
- Oil and gas stocks and crisis response mechanisms;
- Energy efficiency;
- Making the best use of the EU's indigenous and renewable energy resources.

It has to be assumed a highly substantial change in the European energy system over the next decades until 2050. All over Europe the Commission estimates challenges and fundamental changes for the energy system between 2020 and 2050. The EU's new energy and environment policy—agreed by government leaders in their Council meeting in March 2007—established a political agenda to tackle three core energy objectives: sustainability, economic competitiveness and security of supply. European leaders reached a historic agreement for the first time to create a common European energy policy. The resulting Energy Policy for Europe sets out the EU's vision for Energy in the period from 2020 and is based on three fundamental 'pillars' [50]:

- **Sustainability**—to ensure that the EU addresses climate change by reducing its emissions to a level that would limit global temperature increases to 2 °C above pre-industrial levels. The EU will do this by committing to a 20% reduction in greenhouse gas emissions; a 20% improvement in energy efficiency; and deployment of 20% of energy generation from renewable sources, all by 2020. These are known as the 20:20:20 targets.
- **Security of Supply**—to minimize the EU's vulnerability concerning imports, shortfalls in supply, possible energy crises and uncertainty on future supply. The EU will do this by introducing measures which ensure solidarity between member states, the diversification of supply sources and transportation routes, and improved security of oil stocks, gas supply and electricity generation.
- **Competitiveness**—to ensure the effective implementation of the internal energy market. The EU will do this by introducing reforms to ensure clearer separation of gas and electricity transmission from production and supply, thereby creating a more competitive market and by harmonizing the competencies of national energy market regulators and ensuring their collaboration.

A triad of specific policies addresses these challenges: first, the 20/20/20 *targets* of the EU; then, the Second Strategic Energy Review of the European Commission; and finally, plans to liberalize energy markets. In December 2008 the European Parliament adopted a set of legislative documents (the so called EU climate and energy package) for transforming Europe gradually into a low-carbon economy and increasing energy security. An agreement has been reached on legally binding targets, by 2020 [51]:

- to cut GHG emissions by 20% compared to 1990,
- to establish a 20% share for renewable energy in final energy consumption and the share of biofuels up to 10% in transport fuels, and
- to achieve a 20% reduction in energy consumption by 2020 (to improve energy efficiency).

Regarding the reduction of GHG emissions, the package contains an offer to go further and commit to a 30% cut in the event of a satisfactory international agreement being reached.

Directive 2009/28/EC sets legally binding targets for each EU member state, in order to reach the EU aggregated target of a 20% share of renewable energy by 2020 [52]. It creates cooperation mechanisms for achieving the targets in a cost effective way. Several administrative barriers and other burdens will be removed, confirming the 10% target for renewables in transport, and biofuels sustainability criteria are fixed to ensure that only those biofuels are supported that have no negative environmental impact. The directive also has implications for small-scale emitters in sectors such as transport, buildings, agriculture and waste. By 2020, emissions from these areas are to be reduced by an average of 10% compared to 2005, divided between member states according to differences in GDP per capita. National targets were set for member states, together with a linear legally binding trajectory for the period 2013–2020 with annual monitoring and compliance checks.

Directive 2009/31/EC establishes a legal framework for the environmentally safe geological storage of carbon dioxide (CO_2) to contribute to the fight against climate change [53].

Directive 2009/30/EC provides a set of binding targets for the emissions from the fleet of new cars which is an important tool for meeting emission targets in the non-ETS sectors. The directive sets targets to ensure that emissions from the new car fleet are reduced to an average of 120 g CO_2/km. The long-term target is set to 95 g CO_2/km to be reached by 2020 [54].

Decision 406/2009/EC lays down the minimum contribution of EU member states to meeting the GHG emission reduction commitment of the Community for the period from 2013 to 2020 for GHG emissions covered by this decision, and rules on making these contributions and for the evaluation thereof [55].

To cope with the increasing dependence on imported energy, the European Union (EU) must bring into play a new energy policy, the three main objectives of which are competitiveness, sustainable development and security of supply. It is in this wider context of an integrated and coherent energy policy and, in particular, of promoting renewable energy sources that the European Commission has adopted Biomass Action Plan in 2005. The promotion of bioenergy is a top priority on the political agenda of the EU and most member states. However, the progress in terms of actual market deployment is still dissatisfactory. Many of the existing market barriers have their origin in insufficient policy frameworks on the national level. Recent policy initiatives aim at overcoming these barriers including the European Biomass Action Plan (BAP).

The biomass, i.e. all organic plant and animal products used to produce energy (or in agriculture), currently accounts for around half (44 to 65%) of all renewable energy used in the EU. Biomass currently meets 4% of the EU's energy needs (69 million tonnes of oil equivalent (toe)). The aim is to increase biomass use to around 150 million toe by 2010. An increase of this magnitude could bring such benefits as: diversifying Europe's energy supply; significantly reducing greenhouse gas emissions (209 million - tonnes); direct employment for 250 to 300,000 people; potentially lowering the price of oil as a result of lower demand. According to EC projections, biomass would contribute to at least 50% of the RES 20% target by 2020. The Commission's proposal for the Seventh Framework Programme gives a high priority to biomass research. The Commission plans in particular to look at how best to take forward research into the optimization of agricultural and woody crops for energy purposes, and into conversion processes. Lastly, through the Intelligent energy for Europe programme (2007–2013), the Commission will support the dissemination of techniques that reflect European objectives for renewable energy.

As EU has set itself ambitious targets to achieve clean and secure energy for tomorrow. An optimal use of available tools is necessary to meet these targets. A wide range of technologies and methods exist to improve energy efficiency, turn renewables into viable energy sources and reduce emissions. However, market conditions prevent them from reaching their full potential. This is where the Intelligent Energy-Europe programme comes in. The Intelligent Energy-Europe (IEE) programme is giving a boost to clean and sustainable solutions. It supports their use and dissemination and the Europe-wide exchange of related knowledge and know-how. Targeted funding is provided for creative projects putting this idea into practice. The projects help to further the three main objectives [51]:

- promoting energy efficiency and encouraging the rational use of energy sources;
- increasing the use of new and renewable energy sources as well as encouraging energy diversification;
- stimulating energy efficiency and renewables in the field of transport.

Intelligent Energy-Europe (IEE) was launched in 2003 by the European Commission. The programme is part of a broad push to create an energy-intelligent future in EU. It supports mainly EU energy efficiency and renewable energy policies. This programme creates a better conditions for a more sustainable energy future in areas as varied as renewable energy, energy-efficient buildings, industry, consumer products and transport. It is expected that by doing this, Europe will also boost its competitiveness, security of energy supply, and innovation. Running until 2013, the programme is open to all EU Member States, plus Norway, Iceland, Liechtenstein, Croatia and the Former Yugoslav Republic of Macedonia. A budget of € 730 million is available to fund projects and put into place a range of European portals, facilities and initiatives. A large part of the programme budget is made available through annual calls for proposals to support projects putting the concept of 'intelligent energy' in practice. Carried out by public, private or non-governmental European organizations, they support three main objectives—more energy efficiency, more renewables, and better transport and mobility. This covers for instance new training schemes, promotion campaigns, or the transfer of good practices between EU countries.

There are funding opportunities for use of renewables from EU structural funds. The EU structural funds are supposed to be the major financial tool towards development of renewables and energy efficiency in the new EU member states. The new programming period was set to start from 2007. The whole year 2007 and even the largest part of the 2008 were devoted to the preparation of programming documents (operating plans) on national level and final approval at European Commission. Thus the first calls for applications were launched only in 4th quarter of 2008. Though the use of structural funds for renewable energy (RE) and energy efficiency (EE) is too low to give a substantial impact for sustainable development; but valuable specific projects have been funded with structural funds.

European Regional Development Fund (ERDF) was used for reducing isolation through improved access to energy systems, enhanced inter-operability of national and regional systems and networking, exchange of experiences and good practice. The distribution of the total EU cohesion policy budget of € 347 billion (current prices) for 2007–2013 was the following: Convergence objective −81.5%; Competitiveness and Employment objective −16.0%; European Territorial Cooperation objective −2.5%

In Lithuania according Operational Programme for Cohesion Promotion from ERDF 1 475 mil. EUR were allocated for Priority 3 *Environment and sustainable development, Measure 3.5: Energy efficiency and use of renewable energy sources*. Actions supported (Co-financing from ERDF and Country Financing: 85%):

- Refurbishment and renovation of public buildings seeking to enhance their energy characteristics.
- Construction of new Combined Heat and Power (CHP) and renovation of existing CHP seeking to increase their efficiency and capacity.
- Renovation and modernization of heat boilers supplying district heating seeking to increase their efficiency and implement cogeneration. Refurbishment of CHP and heat boilers to use renewable energy sources or other more environmentally friendly fuels.

There are also funding opportunities from EU Cohesion Policy in 2014–2020. For Broad Thematic Objectives vs. Narrow Investment Priorities European Regional Development Priority 4 supporting the shift towards a low-carbon economy in all sectors includes:

- promoting the production and distribution of renewable energy sources;
- promoting energy efficiency and renewable energy use in SMEs;
- supporting energy efficiency and renewable energy use in public infrastructures and in the housing sector;
- developing smart distribution systems at low voltage levels;
- promoting low-carbon strategies for urban areas.

4. Lithuanian energy sector

Lithuanian energy sector distinguished with huge energy generation capacities overcoming national energy demand until 2010. However the closure of Ignalina Nuclear Power Plant (NPP) in the end of 2009 drastically changed the situation in Lithuanian energy sector and Lithuania became dependent on electricity import. Natural gas consumption in its energy mix has increased for the production of electricity (Lithuania is totally dependent on imported natural gas from Russia) and the price of electricity for customers has increased by more than 30%.

Important features of the Lithuanian energy sector are the following: high dependence on primary energy supply from one country; absence of interconnections with Western energy systems; dramatic changes in the structure of power generating capacities beyond 2010; still comparatively small contribution from renewable and local energy resources, etc.

Based on studies conducted in Lithuania [56,57] during the period 2008–2020 consumption of renewable energy sources would increase up to 1950 toe or by 2.3 times. However, owing to the absence of appropriate legal regulation, national renewable energy action plan, delayed or reduced financial support and striking decline of the Lithuanian economy in 2009–2010 possibilities to use renewable energy sources at maximal extent are limited. In a case of rational scenario it is foreseen that total their amount will increase up to 1600 toe in 2020. The 23% target for the overall share of renewable energy sources from the gross country's final energy consumption, the 15% target for renewable energy in the transport sector and the 12% target for the share of electricity generation from renewable energy sources in 2020 could be appropriate and achievable objectives for Lithuania. Increased investments in the renewable energy sector will reduce dependence on imported fossil fuels, will create favorable environment for development and implementation of new energy conversion technologies, mitigation of climate change, creation of new working places etc.

5. Preliminaries for fuzzy MULTIMOORA method

This section briefly presents the main concepts of fuzzy logics and the fuzzy MULTIMOORA method. These instruments were employed to compare the previously discussed alternatives, i.e. energy crops, against multiple criteria expressed in different types of information.

Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling uncertain systems. A fuzzy set is an extension of a crisp set. Crisp sets only allow full membership or non-membership, while fuzzy sets allow partial membership. The theoretical fundaments of fuzzy set theory are overviewed in [28,30,58–63].

As already said earlier, Multi-Objective Optimization by Ratio Analysis (MOORA) method was introduced by Brauers and Zavadskas [11] on the basis of previous research. Brauers and Zavadskas [12] extended the method and in this way it became more robust as MULTIMOORA (MOORA plus the full multiplicative form).

The fuzzy MULTIMOORA was introduced by Brauers et al. [19]. In this study we will employ the modified version as reported by Baležentis et al. [63]. The fuzzy MULTIMOORA begins with fuzzy decision matrix $\tilde{X}$, where $\tilde{x}_{ij}=(x_{ij1},x_{ij2},x_{ij3})$ are aggregated responses of alternatives on objectives.

5.1. The fuzzy Ratio System

The Ratio System defines normalization of the fuzzy numbers $\tilde{x}_{ij}$ resulting in the matrix of dimensionless numbers. The normalization is performed by comparing appropriate values of fuzzy numbers:

$$\tilde{x}^*_{ij}=(x^*_{ij1},x^*_{ij2},x^*_{ij3})=\begin{cases} x^*_{ij1}=x_{ij1}\Big/\sqrt{\sum_{i=1}^{m}[(x_{ij1})^2+(x_{ij2})^2+(x_{ij3})^2]} \\ x^*_{ij2}=x_{ij2}\Big/\sqrt{\sum_{i=1}^{m}[(x_{ij1})^2+(x_{ij2})^2+(x_{ij3})^2]},\forall i,j. \\ x^*_{ij3}=x_{ij3}\Big/\sqrt{\sum_{i=1}^{m}[(x_{ij1})^2+(x_{ij2})^2+(x_{ij3})^2]} \end{cases} \tag{1}$$

The normalization is followed by computation of summarizing ratios $\tilde{y}^*_i$ for each ith alternative. The normalized ratios are added or subtracted as reported in [63]:

$$\tilde{y}^*_i=\sum_{j=1}^{g}\tilde{x}^*_{ij}\ominus\sum_{j=g+1}^{n}\tilde{x}^*_{ij}, \tag{2}$$

where $g=1,2,\ldots,n$ stands for number of indicators to be maximized. Then each ratio $\tilde{y}^*_i=(y^*_{i1},y^*_{i2},y^*_{i3})$ is defuzzified:

$$BNP_i=\frac{(y^*_{i3}-y^*_{i1})+(y^*_{i2}-y^*_{i1})}{3}+y^*_{i1}, \tag{3}$$

where BNP_i denotes the best non-fuzzy performance value of the ith alternative. Consequently, the alternatives with higher BNP values are attributed with higher ranks.

5.2. The fuzzy Reference Point

The fuzzy Reference Point approach is based on the fuzzy Ratio System. The Maximal Objective Reference Point (vector) $\tilde{r}$ is found according to ratios found in Eq. (1). The jth coordinate of the reference point resembles the fuzzy maximum or minimum of the jth criterion $\tilde{x}^+_j$, where

$$\begin{cases} \tilde{x}^+_j=(\max_i x^*_{ij1},\max_i x^*_{ij2},\max_i x^*_{ij3}), j\le g; \\ \tilde{x}^+_j=(\min_i x^*_{ij1},\min_i x^*_{ij2},\min_i x^*_{ij3}), j>g. \end{cases} \tag{4}$$

Then the every element of normalized responses matrix is recalculated and final rank is given according to deviation from the reference point (Eq. 6) and the Min–Max Metric of Tchebycheff:

$$\min_i(\max_j d(\tilde{r}_j,\tilde{x}^*_{ij})). \tag{5}$$

5.3. The fuzzy full multiplicative form

Overall utility of the ith alternative can be expressed as dimensionless number by employing Eq. (5):

$$\tilde{U}'_i=\tilde{A}_i\oslash\tilde{B}_i, \tag{6}$$

where $\tilde{A}_i=(A_{i1},A_{i2},A_{i3})=\prod_{j=1}^{g}\tilde{x}_{ij}$, $i=1,2,\cdots,m$ denotes the product of objectives of the ith alternative to be maximized with $g=1,\cdots,n$ being the number of objectives (structural indicators) to be maximized and where $\tilde{B}_i=(B_{i1},B_{i2},B_{i3})=\prod_{j=g+1}^{n}\tilde{x}_{ij}$ denotes the product of objectives of the ith alternative to be minimized with $n-g$ being the number of objectives (indicators) to be minimized. Since overall utility $\tilde{U}'_i$ is fuzzy number, one needs to defuzzify them to rank the alternatives [63]. The higher the BNP, the higher the rank of certain alternative.

Thus, the fuzzy MULTIMOORA summarizes fuzzy MOORA (i.e. fuzzy Ratio System and fuzzy Reference Point) and the fuzzy Full Multiplicative Form as described by the dominance theory, cf. [18]. As one can note, the fuzzy Reference Point prevents the fuzzy MULTIMOORA from becoming a fully compensatory technique. Whereas the fuzzy Ratio System and the fuzzy Full

Multiplicative Form are fully compensatory methods, the fuzzy Reference Point is not one. For the latter method is based on Min–Max metric of Tchebycheff, which identifies certain alternatives peculiar with relative backwardness in either of criteria. Hence, the fuzzy MULTIMOORA is quite an effective tool for assessing sustainability of various phenomena resulting in unbiased ranking of alternatives.

6. Construction of the fuzzy decision matrix: criteria and alternatives

According to the biomass energetic agent, these crops are grouped into starch crops (viz. wheat, grain maize, and barley), oil crops (viz. rape) and ligno-cellulosic crops (short rotation crops, e.g. coppice-SRC of willow, poplar or miscanthus, switchgrass, and reed canary grass, and annual crops like hemp, whole-plant cereals, and perennial grasses), see Table 1. The energy crops belonging to sugar, starch, and oil categories all are rotational arable crops commonly grown as food and feed crops. From an energetical perspective, they are those best suitable for the production of biofuels (first generation) and biogas. The use of these crops for biomass and their potential impacts on environment and farmland biodiversity does not cause a different impact from that caused by using the latter plants for feed and food production. The ligno-cellulose crops all are perennial crops that became attractive with the introduction of second generation technology. The use of grassland cuttings for energy purposes is expected to offer a good opportunity to conserve semi natural grasslands from natural succession and therefore prevent the loss of species-rich open habitats which share occupies ca. 50% of agricultural lands in Lithuania. Crop productivity indices, namely yield of dry materials (DM), energy yield, photosynthesis type, energetic value were considered.

The prioritization of crops according to different risk parameters is based on information on agri-environmental pressures per Boreal–Nemoral environmental zone and further reference-based knowledge on the present land use [64]. Indeed, it is the environmental stratification of Europe that divides the region into zones with a homogeneous, pedo-geo-climatic character. The main environmental and farming system characteristics per environmental zone are: climatic suitability, present land use, present farming systems, present environmental problems. The main biomass crops are prioritized according to their environmental pressures for Boreal–Nemoral environmental zone, which covers Lithuanian territory. The preservation of environmentally orientated farming was considered essential both for easing environmental pressures of farming and for preserving extensive land use categories that are important for farmland biodiversity and landscapes. The environmental impact of different energy crops can be assessed via a number of pressure indicators that ideally would be defined for each environmental zone. This results in the selection of a biomass crop mix per environmental zone which should not impose any additional pressure on environmental resources and farmland biodiversity. The pressure indicators used to determine the expected environmental impact of bioenergy crops suitable for growing in Boreal–Nemoral environmental zone relevant for Lithuania encompassed erosion, soil carbon sequestration, water abstraction, N requirement. To conclude, the integrated framework developed in this study should foster environmentally compatible biomass production in agriculture.

The values of decision matrix elements were approximated with respect to the literature analysis and EU agri-environmental policy objectives [64–69]. The taxonomy of the seven decision

Table 1
The taxonomy of criteria employed for fuzzy comparison of energy crops.

Types of Criteria	Benefit	Cost
Linguistic	1. Photosynthesis type 2. Soil carbon sequestration 5. Erosion control	3. Water adaptation 4. N input requirement
Numeric	6. DM, t ha-1 7. Energy yield, GJ ha-1	—

Table 2
Values of linguistic variables for energy crop comparison.

No.	Crop	1. Photosynthesis type MAX	2. Soil carbon sequestration MAX	3. Water adaptation MIN	4. N input requirement MIN	5. Erosion control MAX
1	Rapeseed (*Brassica napus* L.)	C3	M	L	H	L
2	Maize (*Zea mays* L.) biomass	C4	H	L	H	M
3	Corn cereals (wheat *Triticum aestiva*, barely *Hordeum vulgare* L.)	C3	M	L	H	M
4	Triticale (× *Triticosecale*) biomass	C3	M	L	H	M
5	Switchgrass (*Panicum virgatum* L.)	C4	H	L	ML	H
6	Topinambour biomass (*Helianthus tuberosus* L.)	C3	M	L	M	M
7	Industrial hemp (*Cannabis sativa* L.)	C3	M	L	H	G
8	Permanent grasses (*Festuca arundinacea* L.; *Bromus tectorum* L.; *Phalaris arundinacea* L.; *Dactylis glomerata* L.)	C3	M	L	ML	H
9	Mixes *Festuca arundinacea* L.+*Melilotus alba* L.	C3	M	L	ML	H
10	*Phalaris arundinacea* L.	C3	M	M	ML	H
11	Reed canary grass (*Phalaris arundicancea* L.)	C3	H	M	ML	H
12	Giant silver grass (*Miscanthus giganteus*)	C4	H	L	ML	H
13	Giant reed (*Arundo donax* L.)	C3	H	M	ML	H
14	Giant knotweed (*Reynoutria sacchalinensis* (F. Schmidt) Nakai); Japanese knotweed (*Reynoutria japonica* Houtt. (Ronse Decr.))	C3	H	M	H	M
15	*Galega orientalis*+*Phalaris arundinacea*	C3	M	M	L	H
16	*Artemisija vulgaris* L.	C3	L	L	L	M
17	Nettle *Urtica dioica* L.	C3	M	L	H	M
18	Sosnovsky cowparsnip (*Heracleum sosnowskyi*)	C3	M	L	M	M
19	Cup plant (*Siphium perfoliatum* L.)	C3	M	L	L	H
20	Virginia mallow (*Sida hermaphrodita* L. Rusby)	C3	M	L	L	M
21	SRC Willow (*Salix viminalis* L.)	C3	M	M	L	M
22	SRC Black poplar (*Populus nigra* L.)	C3	M	L	L	M

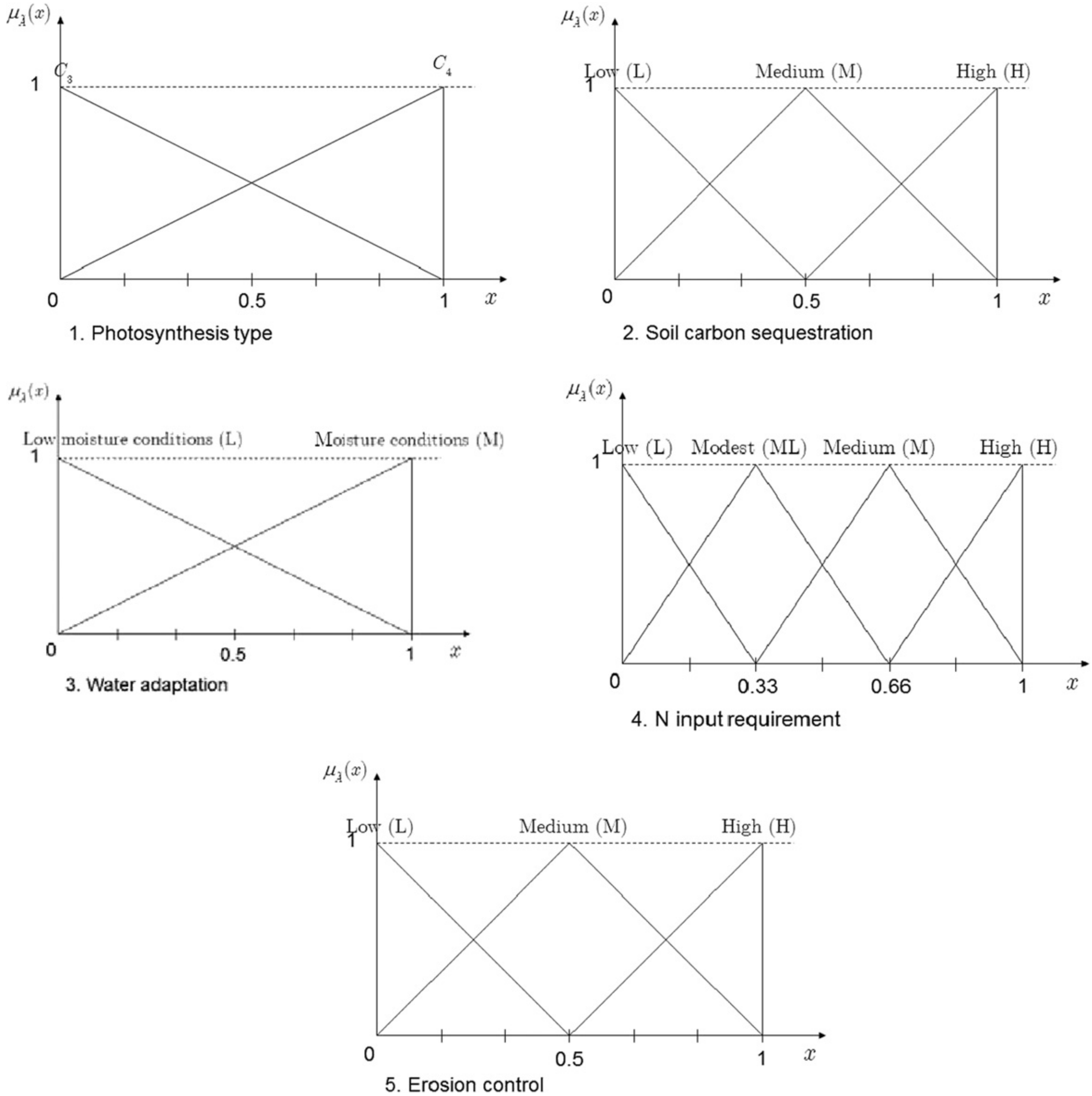

Fig. 1. Linguistic term sets and respective fuzzy numbers for linguistic criteria.

criteria employed for fuzzy prioritization of energy crops is given in Table 1. Cost criteria should be minimized, whereas benefit criteria approach their optimal value at the maximum. As one can note the criteria can be classified into linguistic and numeric ones. Furthermore, the two linguistic inputs, namely water adaptation and N input requirement, were cost ones, whereas both numeric criteria were benefit ones. The fuzzy MCDM method, therefore, becomes a suitable tool to handle the hybrid data and one can obtain the most sustainable solution.

Table 2 summarizes the linguistic information about energy crop species under comparison. Linguistic criteria were expressed in linguistic labels presented in Fig. 1. To be specific, the two criteria (viz. photosynthesis type and water adaptation) were expressed in two-point scale, the other two (viz. soil carbon sequestration and erosion control) were mapped onto three-point scale, whereas the remaining one (soil carbon sequestration) was specific with the maximal granularity of four labels. Indeed, these labels were translated into respective triangular fuzzy numbers.

The numeric indicators were defined in two ways with respect to available information. In case only mean values, x, of certain criterion were reported for separate species in the literature, we allowed the fuzziness of 10% and thus corrected the upper and lower bounds of the triangular fuzzy number in the following way: $(0.9x, x, 1.1x)$. As for those plant species which had certain intervals, $[l,u]$, for their numeric criteria, the triangular numbers were formed in the following manner: $(l,l+u/2,u)$.

Table 3 presents the initial decision matrix, where data are translated into respective fuzzy numbers. This decision matrix will be analyzed by the means of fuzzy MULTIMOORA method to identify the most sustainable

7. Application of the fuzzy MULTIMOORA for crop assessment

This section presents the application of the fuzzy MULTIMOORA for an integrated assessment of energy crops. As it was mentioned before, the fuzzy MULTIMOORA consists of the three parts, viz. the fuzzy Ratio System, the fuzzy Reference Point, and the fuzzy Multiplicative Form. The first two methods use the normalized data, whereas the fuzzy Multiplicative form does not require the data to be normalized (see [70]). The initial fuzzy decision matrix (Table 3) was normalized by employing Eq. 9. Table 4 presents the normalized data.

Table 3
Initial fuzzy decision matrix.

Crops	Criteria						
	1. Photosynthesis type MAX	2. Soil carbon sequestration MAX	3. Water adaptation MIN	4. N input requirement MIN	5. Erosion control MAX	6. DM, t ha-1 MAX	7. Energy yield, GJ ha-1 MAX
1.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0.66, 1, 1)	(0, 0, 0.5)	(1.8, 2, 2.2)	(50.4, 56, 61.6)
2.	(0, 1, 1)	(0.5, 1, 1)	(0, 0, 1)	(0.66, 1, 1)	(0, 0.5, 1)	(17.1, 19, 20.9)	(178.2, 198, 217.8)
3.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0.66, 1, 1)	(0, 0.5, 1)	(3.7, 4.55, 5.4)	(104, 113.5, 123)
4.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0.66, 1, 1)	(0, 0.5, 1)	(6.84, 7.6, 8.36)	(117, 130, 143)
5.	(0, 1, 1)	(0.5, 1, 1)	(0, 0, 1)	(0, 0.33, 0.66)	(0.5, 1, 1)	(9.72, 10.8, 11.88)	(118.8, 132, 145.2)
6.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0.33, 0.66, 1)	(0, 0.5, 1)	(5.62, 6.24, 6.86)	(63.9, 71, 78.1)
7.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0.66, 1, 1)	(0, 0.5, 1)	(13.32, 14.8, 16.28)	(170.1, 189, 207.9)
8.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0, 0.33, 0.66)	(0.5, 1, 1)	(6, 8.3, 10.6)	(100, 125, 150)
9.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0, 0.33, 0.66)	(0.5, 1, 1)	(14.8, 14.15, 13.5)	(250, 262.05, 274.1)
10.	(0, 0, 1)	(0, 0.5, 1)	(0, 1, 1)	(0, 0.33, 0.66)	(0.5, 1, 1)	(7.5, 7.95, 8.4)	(101.3, 111.55, 121.8)
11.	(0, 0, 1)	(0.5, 1, 1)	(0, 1, 1)	(0, 0.33, 0.66)	(0.5, 1, 1)	(10.35, 11.5, 12.65)	(121.5, 135, 148.5)
12.	(0, 1, 1)	(0.5, 1, 1)	(0, 0, 1)	(0, 0.33, 0.66)	(0.5, 1, 1)	(9.45, 10.5, 11.55)	(144, 160, 176)
13.	(0, 0, 1)	(0.5, 1, 1)	(0, 1, 1)	(0, 0.33, 0.66)	(0.5, 1, 1)	(27, 30, 33)	(121.5, 135, 148.5)
14.	(0, 0, 1)	(0.5, 1, 1)	(0, 1, 1)	(0.66, 1, 1)	(0, 0.5, 1)	(8.6, 9.8, 11)	(123.3, 137, 150.7)
15.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0, 0, 0.33)	(0.5, 1, 1)	(9.5, 10.6, 11.66)	(131.67, 146.3, 160.93)
16.	(0, 0, 1)	(0, 0, 0.5)	(0, 0, 1)	(0, 0, 0.33)	(0, 0.5, 1)	(5.04, 5.6, 6.16)	(113.4, 126, 138.6)
17.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0.66, 1, 1)	(0, 0.5, 1)	(5.6, 7.65, 9.7)	(98.1, 109, 119.9)
18.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0.33, 0.66, 1)	(0, 0.5, 1)	(10.62, 11.8, 12.98)	(124.2, 138, 151.8)
19.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0, 0, 0.33)	(0.5, 1, 1)	(12.42, 13.8, 15.18)	(174.6, 194, 213.4)
20.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0, 0, 0.33)	(0, 0.5, 1)	(13.14, 14.6, 16.06)	(122.4, 136, 149.6)
21.	(0, 0, 1)	(0, 0.5, 1)	(0, 1, 1)	(0, 0, 0.33)	(0, 0.5, 1)	(6.48, 7.2, 7.92)	(110.7, 123, 135.3)
22.	(0, 0, 1)	(0, 0.5, 1)	(0, 0, 1)	(0, 0, 0.33)	(0, 0.5, 1)	(6.75, 7.5, 8.25)	(112.5, 125, 137.5)

Table 4
Normalized fuzzy decision matrix and fuzzy Maximal Objective Reference Point (MORP).

Crops	Criteria						
	1. MAX	2. MAX	3. MIN	4. MIN	5. MAX	6. MAX	7. MAX
1.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0.133, 0.202, 0.202)	(0, 0, 0.084)	(0.018, 0.02, 0.022)	(0.043, 0.047, 0.052)
2.	(0, 0.2, 0.2)	(0.088, 0.175, 0.175)	(0, 0, 0.192)	(0.133, 0.202, 0.202)	(0, 0.084, 0.168)	(0.173, 0.192, 0.211)	(0.151, 0.167, 0.184)
3.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0.133, 0.202, 0.202)	(0, 0.084, 0.168)	(0.037, 0.046, 0.055)	(0.088, 0.096, 0.104)
4.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0.133, 0.202, 0.202)	(0, 0.084, 0.168)	(0.069, 0.077, 0.084)	(0.099, 0.11, 0.121)
5.	(0, 0.2, 0.2)	(0.088, 0.175, 0.175)	(0, 0, 0.192)	(0, 0.067, 0.133)	(0.084, 0.168, 0.168)	(0.098, 0.109, 0.12)	(0.1, 0.112, 0.123)
6.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0.067, 0.133, 0.202)	(0, 0.084, 0.168)	(0.057, 0.063, 0.069)	(0.054, 0.06, 0.066)
7.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0.133, 0.202, 0.202)	(0, 0.084, 0.168)	(0.135, 0.149, 0.164)	(0.144, 0.16, 0.176)
8.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0, 0.067, 0.133)	(0.084, 0.168, 0.168)	(0.061, 0.084, 0.107)	(0.085, 0.106, 0.127)
9.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0, 0.067, 0.133)	(0.084, 0.168, 0.168)	(0.149, 0.143, 0.136)	(0.211, 0.222, 0.232)
10.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0.192, 0.192)	(0, 0.067, 0.133)	(0.084, 0.168, 0.168)	(0.076, 0.08, 0.085)	(0.086, 0.094, 0.103)
11.	(0, 0, 0.2)	(0.088, 0.175, 0.175)	(0, 0.192, 0.192)	(0, 0.067, 0.133)	(0.084, 0.168, 0.168)	(0.105, 0.116, 0.128)	(0.103, 0.114, 0.126)
12.	(0, 0.2, 0.2)	(0.088, 0.175, 0.175)	(0, 0, 0.192)	(0, 0.067, 0.133)	(0.084, 0.168, 0.168)	(0.095, 0.106, 0.117)	(0.122, 0.135, 0.149)
13.	(0, 0, 0.2)	(0.088, 0.175, 0.175)	(0, 0.192, 0.192)	(0, 0.067, 0.133)	(0.084, 0.168, 0.168)	(0.273, 0.303, 0.333)	(0.103, 0.114, 0.126)
14.	(0, 0, 0.2)	(0.088, 0.175, 0.175)	(0, 0.192, 0.192)	(0.133, 0.202, 0.202)	(0, 0.084, 0.168)	(0.087, 0.099, 0.111)	(0.104, 0.116, 0.127)
15.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0, 0, 0.067)	(0.084, 0.168, 0.168)	(0.096, 0.107, 0.118)	(0.111, 0.124, 0.136)
16.	(0, 0, 0.2)	(0, 0, 0.088)	(0, 0, 0.192)	(0, 0, 0.067)	(0, 0.084, 0.168)	(0.051, 0.057, 0.062)	(0.096, 0.107, 0.117)
17.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0.133, 0.202, 0.202)	(0, 0.084, 0.168)	(0.057, 0.077, 0.098)	(0.083, 0.092, 0.101)
18.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0.067, 0.133, 0.202)	(0, 0.084, 0.168)	(0.107, 0.119, 0.131)	(0.105, 0.117, 0.128)
19.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0, 0, 0.067)	(0.084, 0.168, 0.168)	(0.125, 0.139, 0.153)	(0.148, 0.164, 0.18)
20.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0, 0, 0.067)	(0, 0.084, 0.168)	(0.133, 0.147, 0.162)	(0.104, 0.115, 0.127)
21.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0.192, 0.192)	(0, 0, 0.067)	(0, 0.084, 0.168)	(0.065, 0.073, 0.08)	(0.094, 0.104, 0.114)
22.	(0, 0, 0.2)	(0, 0.088, 0.175)	(0, 0, 0.192)	(0, 0, 0.067)	(0, 0.084, 0.168)	(0.068, 0.076, 0.083)	(0.095, 0.106, 0.116)
Fuzzy MORP	(0, 0.2, 0.2)	(0.088, 0.175, 0.175)	(0, 0, 0.192)	(0, 0, 0.067)	(0.084, 0.168, 0.168)	(0.273, 0.303, 0.333)	(0.211, 0.222, 0.232)

Firstly, the ranking of crop species was performed in accordance with the fuzzy ratio System. The normalized data, therefore, were aggregated by the virtue of Eq. 2 and defuzzified according to Eq. 3. The plant species were ranked in decreasing order of the crisp values (Table 5). As one can note, giant reed (*Arundo donax* L.), giant silver grass (*Miscanthus gigantheus*), *Festuca arundinacea*+*Melilotus alba*, Cup plant (*Siphium perfoliatum* L.), and Switchgrass (*Panicum virgatum*) were considered as the most suitable alternatives, in that order.

Secondly, the fuzzy Maximal Objective Reference Point (MORP) was defined (cf. Eq. 4 and the last row of Table 4). The deviations from the MORP was calculated by employing Eq. 5 for each of alternatives (Table 6). The alternatives were then ranked in ascending order of the maximal deviation. Giant reed (*Arundo donax* L.), Virginija mallow (Sida hermaphrodita L.Rusby), Industrial hemp (*Cannabis sativa* L.), Maize biomass, and Festuca arundinacea+Melilotus alba were placed at the top according to the fuzzy Reference Point approach.

Thirdly, the alternatives (i.e. crop species) were ranked according to the fuzzy Multiplicative Form as described by Eq. 6. In order to carry out reasonable multiplication and division operations, zero values in the decision matrix were transformed into values of

Table 5
The fuzzy ratio system.

Crops	Sum of fuzzy benefit indicators	Sum of fuzzy cost indicators	$\tilde{y}_i^*$	BNP_i	Rank
1.	(0.061, 0.155, 0.534)	(0.133, 0.202, 0.394)	(−0.333, −0.046, 0.401)	0.0036	22
2.	(0.411, 0.819, 0.939)	(0.133, 0.202, 0.394)	(0.017, 0.617, 0.805)	0.4752	6
3.	(0.125, 0.314, 0.702)	(0.133, 0.202, 0.394)	(−0.269, 0.112, 0.569)	0.1333	21
4.	(0.168, 0.358, 0.749)	(0.133, 0.202, 0.394)	(−0.226, 0.157, 0.616)	0.1780	18
5.	(0.37, 0.764, 0.786)	(0, 0.067, 0.326)	(0.045, 0.697, 0.786)	0.5048	5
6.	(0.111, 0.295, 0.679)	(0.067, 0.133, 0.394)	(−0.283, 0.162, 0.612)	0.1590	20
7.	(0.278, 0.481, 0.884)	(0.133, 0.202, 0.394)	(−0.116, 0.279, 0.75)	0.3005	12
8.	(0.229, 0.445, 0.777)	(0, 0.067, 0.326)	(−0.096, 0.379, 0.777)	0.3486	10
9.	(0.445, 0.62, 0.911)	(0, 0.067, 0.326)	(0.119, 0.554, 0.911)	0.5240	3
10.	(0.245, 0.43, 0.731)	(0, 0.259, 0.326)	(−0.08, 0.171, 0.731)	0.2705	14
11.	(0.379, 0.574, 0.797)	(0, 0.259, 0.326)	(0.053, 0.315, 0.797)	0.3849	9
12.	(0.389, 0.785, 0.809)	(0, 0.067, 0.326)	(0.063, 0.718, 0.809)	0.5254	2
13.	(0.547, 0.76, 1.002)	(0, 0.259, 0.326)	(0.222, 0.501, 1.002)	0.5715	1
14.	(0.279, 0.474, 0.782)	(0.133, 0.394, 0.394)	(−0.115, 0.08, 0.649)	0.2014	17
15.	(0.291, 0.486, 0.797)	(0, 0, 0.259)	(0.032, 0.486, 0.797)	0.4345	7
16.	(0.147, 0.247, 0.635)	(0, 0, 0.259)	(−0.112, 0.247, 0.635)	0.2529	16
17.	(0.14, 0.341, 0.743)	(0.133, 0.202, 0.394)	(−0.255, 0.139, 0.61)	0.1606	19
18.	(0.212, 0.408, 0.803)	(0.067, 0.133, 0.394)	(−0.182, 0.274, 0.736)	0.2717	13
19.	(0.357, 0.559, 0.877)	(0, 0, 0.259)	(0.098, 0.559, 0.877)	0.5072	4
20.	(0.236, 0.434, 0.832)	(0, 0, 0.259)	(−0.023, 0.434, 0.832)	0.4101	8
21.	(0.159, 0.348, 0.738)	(0, 0.192, 0.259)	(−0.1, 0.156, 0.738)	0.2609	15
22.	(0.163, 0.353, 0.743)	(0, 0, 0.259)	(−0.096, 0.353, 0.743)	0.3291	11

Table 6
The fuzzy reference point.

Crops	Criteria							$\max_j d(\tilde{r}_j, \tilde{x}_{ij}^*)$	Rank
	1. MAX	2. MAX	3. MIN	4. MIN	5. MAX	6. MAX	7. MAX		
1.	0.115	0.072	0.000	0.160	0.119	0.284	0.174	0.284	22
2.	0.000	0.000	0.000	0.160	0.069	0.111	0.054	0.160	3
3.	0.115	0.072	0.000	0.160	0.069	0.258	0.126	0.258	21
4.	0.115	0.072	0.000	0.160	0.069	0.227	0.112	0.227	16
5.	0.000	0.000	0.000	0.054	0.000	0.195	0.110	0.195	9
6.	0.115	0.072	0.000	0.116	0.069	0.241	0.162	0.241	19
7.	0.115	0.072	0.000	0.160	0.069	0.154	0.062	0.160	3
8.	0.115	0.072	0.000	0.054	0.000	0.219	0.116	0.219	13
9.	0.115	0.072	0.000	0.054	0.000	0.163	0.000	0.163	5
10.	0.115	0.072	0.111	0.054	0.000	0.224	0.127	0.224	14
11.	0.115	0.000	0.111	0.054	0.000	0.187	0.107	0.187	8
12.	0.000	0.000	0.000	0.054	0.000	0.198	0.086	0.198	11
13.	0.115	0.000	0.111	0.054	0.000	0.000	0.107	0.115	1
14.	0.115	0.000	0.111	0.160	0.069	0.205	0.106	0.205	12
15.	0.115	0.072	0.000	0.000	0.000	0.197	0.098	0.197	10
16.	0.115	0.124	0.000	0.000	0.069	0.247	0.115	0.247	20
17.	0.115	0.072	0.000	0.160	0.069	0.226	0.129	0.226	15
18.	0.115	0.072	0.000	0.116	0.069	0.184	0.105	0.184	7
19.	0.115	0.072	0.000	0.000	0.000	0.164	0.058	0.164	6
20.	0.115	0.072	0.000	0.000	0.069	0.156	0.107	0.156	2
21.	0.115	0.072	0.111	0.000	0.069	0.231	0.118	0.231	18
22.	0.115	0.072	0.000	0.000	0.069	0.228	0.116	0.228	17

Table 7
The fuzzy multiplicative form.

Crops	$\log_{10}(BNP_i)$	Rank
1.	5.5	22
2.	7.5	14
3.	6.5	21
4.	6.8	18
5.	10.8	8
6.	6.7	20
7.	7.2	16
8.	10.7	9
9.	11.1	2
10.	10.5	12
11.	10.8	6
12.	10.8	5
13.	11.2	1
14.	6.9	17
15.	10.8	7
16.	10.1	13
17.	6.8	19
18.	7.3	15
19.	11.0	3
20.	10.9	4
21.	10.5	11
22.	10.6	10

0.0001. Given large numbers involved in the computing, Table 7 presents the summarized data only. The fuzzy Multiplicative Form suggested Giant reed (*Arundo donax* L.), *Festuca arundinacea*+*Melilotus alba*, Cup plant (*Siphium perfoliatum* L.), Virginia mallow (*Sida hermaphrodita* L.Rusby), and Giant silver grass (*Miscanthus gigantheus*) being the most sustainable choice for energy production.

The theory of dominance was employed to aggregate the three ranks provided for each of alternatives into the single final rank (Table 8). Accordingly, Giant reed (*Arundo donax* L.), *Festuca arundinacea*+*Melilotus alba*, Cup plant (*Siphium perfoliatum* L.), Virginija mallow (*Sida hermaphrodita* L.Rusby), and Giant silver grass (*Miscanthus gigantheus*) were chosen as the most promising crop species in terms of the proposed multi-criteria framework. Therefore, the environmental pressure indicators were combined with the potential biomass crops in order to come to an initial crop-by-crop description of potential crop-mix.

The most promising crops attributed with ranks 1–5 are characteristic with high DM and energy yield (Table 7). Among the five of the best energy crops only giant reed (*Arundo donax* L.) produces biomass via more effective photosynthesis C4 type. Moreover, giant reed (*Arundo donax* L.), giant silver grass (*Miscanthus gigantheus*), *Festuca arundinacea* L.+*Melilotus alba*, cup plant (*Siphium perfoliatum* L.), and switchgrass (*Panicum virgatum* L.) are suitable to preserve the abandoned land—previously arable and extensive grasslands—from afforestation. Giant reed (*Arundo donax* L.) and giant silver grass (*Miscanthus gigantheus*) are energy-valuable crops for optimal energy cropping systems in Lithuania due to high soil carbon sequestration and, thus, GHG emission reduction. Low N input requirement of mix *Festuca arundinacea* L.+*Melilotus alba* indicate its advantageousness. Indeed, good nitrogen fixation is important when reducing nutrient cots and their leaching risks. These top-ranked energy crops with exception of giant reed (*Arundo*

Table 8
The final ranking of energy crops according to fuzzy MULTIMOORA.

No.	Crop	RS	RP	MF	**Final rank**
13.	Giant reed (*Arundo donax* L.)	1	1	1	**1**
9.	*Festuca arundinacea*+*Melilotus alba*	3	5	2	**2**
19.	Cup plant (*Siphium perfoliatum* L.)	4	6	3	**3**
20.	Virginija mallow (*Sida hermaphrodita* L.Rusby)	8	2	4	**4**
12.	Giant silver grass (*Miscanthus gigantheus*)	2	11	5	**5**
5.	Switchgrass (*Panicum virgatum* L.)	5	9	8	**6**
2.	Maize (*Zea mays* L.) biomass	6	3	14	**7**
11.	Reed canary grass (*Phalaris arundicancea* L.)	9	8	6	**8**
15.	*Galega orientalis*+*Phalaris arundinacea*	7	10	7	**9**
8.	Permanent grasses (*Festuca arundinacea; Bromus tectorum; Phalaris arundinacea; Dactylis glomerata*)	10	13	9	**10**
22.	SRC Black poplar (*Populus nigra* L.)	11	17	10	**11**
7.	Industrial hemp (*Cannabis sativa* L.)	12	3	16	**12**
18.	Sosnovsky cowparsnip (*Heracleum sosnowskyi*)	13	7	15	**13**
10.	*Phalaris arundinacea*	14	14	12	**14**
21.	SRC Willow (*Salix viminalis L.*)	15	18	11	**15**
16.	*Artemisija vulgaris* L.	16	20	13	**16**
14.	Giant knotweed (*Reynoutria sacchalinensis* (F. Schmidt) Nakai); Japanese knotweed (*Reynoutria japonica* Houtt. (Ronse Decr.))	17	12	17	**17**
4.	Triticale biomass	18	16	18	**18**
17.	Nettle (*Urtica dioica* L.)	19	15	19	**19**
6.	Topinambour biomass (*Helianthus tuberosus* L.)	20	19	20	**20**
3.	Corn cereals (wheat, barley)	21	21	21	**21**
1.	Rapeseed (*Brassica napus* L.)	22	22	22	**22**

donax L.) show a low water usage and water use efficiency resulting in higher amount of DM per unit of water. Therefore they do not increase water abstraction and thus exclude loss of wetlands and the disappearance of wet habitats. Additionally, all of these crops were prioritized according to the high erosion control which leads to environment-friendly land usage under them.

Less efficiency crops with ranks 6–10 appeared to be switchgrass (*Panicum virgatum* L.), maize (*Zea mays* L.) reed canary grass (*Phalaris arundicancea* L.), mix *Galega orientalis*+*Phalaris arundinacea*, permanent grasses (*Festuca arundinacea; Bromus tectorum; Phalaris arundinacea; Dactylis glomerata*). Their position might be influenced by a lower DM and energy production, or high N input requirement (maize). As referred by EEA, willow vegetation filters are attractive from an economic viewpoint. This is due to reduced willow cultivation costs and also to the fact that willow vegetation filters provide a treatment option that is lower in cost than conventional treatment at sewage plants [3].

8. Conclusions

Exhaustion of fossil fuel resources leads to expansion in researches related to renewable sources of energy which are to alleviate the scarcity of petroleum products as well as to create a healthy environment. This study was aimed at applying the fuzzy multi-criteria decision making method MULTIMOORA for linguistic and numeric prioritization of energy crops under Lithuanian climatic conditions.

This study furthers methodology for environmentally compatible bioenergy production as well as gives practical examples of environmentally beneficial approaches, based on practical experience or scientific knowledge. The main approaches to gaining maximum environmental and energetic benefit from bioenergy cropping are combined in the proposed indicator set. The sustainability of energy cropping was estimated in terms of photosynthesis type, soil carbon sequestration, water adaptation, N input requirement, erosion control, dry mass and energy yield. As a result, several novel crops for a Boreal–Nemoral region, namely Lithuania, were identified by considering multiple *environmentally compatible* indices by the virtue of the multi-criteria ranking. Besides giant reed (*Arundo donax* L.), mixed *Festuca arundinacea*+*Melilotus alba*, cup plant (*Siphium perfoliatum* L.), virginia mallow (Sida hermaphrodita L.Rusby), and giant silver grass (*Miscanthus gigantheus*) they include maize biomass, reed canary grass (*Phalaris arundicancea* L.), mixe *Galega orientalis* Lam.+*Phalaris arundinacea* L., permanent grasses (*Festuca arundinacea*; *Bromus tectorum; Phalaris arundinacea* L.; *Dactylis glomerata* L.). Lignified SRC, viz. black poplar (*Populus nigra* L.) and willow (*Salix viminalis* L.), attracted particular interest as vegetation filters for sewage.

This research is likely to be further incentivised by foreseeing prospective biomass crops and their competition with food and feed production. Indeed, considerable research on land re-allocation and fieldwork are still required in Lithuania to obtain more certain estimates for multi-criteria decision making.

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